NATIONAL BUREAU OF STANDARDS REPORT

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LABORATORY–FIELD COMPARISON OF BUILT-UP ROOFING MEMBRANES

U.S. DEPARTMENT OF COMMERCE
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1. INTRODUCTION

Correlation of the results of laboratory and field practice has been of primary interest to both the research technician and users of materials in the building industry. When a new laboratory developed concept, such as "Thermal-Shock Resistance Factor," is proposed, extensive testing of laboratory prepared and field prepared samples is necessary to determine the validity of the concept. In this connection a study to compare the values of the thermal-shock resistance factors of field prepared and laboratory prepared samples of built-up roofing systems was initiated. The program was conducted by the Building Research Division of the National Bureau of Standards in cooperation with the Midwest Roofing Contractors Association. Samples of nine built-up roof systems were prepared at a job site in Knasas City, Mo. by employees of the Sellers and Marquis Roofing Company. Materials similar to those used in the preparation of the samples in the field were furnished to the National Bureau of Standards laboratories in Gaithersburg, Maryland. Samples were prepared using these materials under controlled conditions by the National Bureau of Standards personnel. The specimens were tested to determine the engineering properties from which the thermal-shock resistance factors were calculated.

1.1 Historical Background

Investigations by Cullen [1][1/] indicated that movements occur in bituminous built-up roofing under temperature changes and he suggested that the stresses

[1/] Figures in brackets indicate the literature references at the end of this paper.

which result are contributing factors in tension splitting. He proposed the utilization of a thermal-shock resistance factor, calculated from engineering properties of the membrane, to predict the ability of the membrane to withstand the forces induced by temperature change [2].

Cullen and Boone reported the values of the engineering properties [3] of laboratory-prepared and field-obtained bituminous built-up membranes and related tension splits to climate, thermal characteristics of the substrate, orientation of the reinforcing felt, and the composition of the built-up membrane. A comparison of results obtained between the laboratory-prepared and specimens obtained from built-up roofing systems of known in-service behavior, indicated that the higher the value for the thermal-shock resistance factor, the more resistant the membrane was to tension splitting due to thermally induced forces.

The purpose of this investigation was to compare the values of the engineering properties and, hence, the thermal-shock resistance factor of roofing specimens prepared under closely controlled laboratory conditions by technical personnel with those constructed by roofers in accordance with accepted roofing practices under job-site conditions.

2. EXPERIMENTAL DETAILS

2.1 Sample Preparation

a) Field Samples

A roofing crew of the Sellers and Marquis Roofing Company, under the supervision of Mr. Paul Morris, prepared the field samples. A member of the NBS staff observed the sample preparation. The asphalt and the roofing felts were obtained either from the job-site or from the local warehouses. The asphalt had a softening point of 190°F. The field samples were prepared out

of doors on a warm day in August, 1967 and are listed in Table 1. Specimens of felt were taken from the same rolls for shipment to the NBS laboratory for use in the preparation of laboratory samples. A sample of the asphalt was also shipped to the NBS.

A 3 X 10 foot piece of roofing felt was placed on a smooth insulation board that had been coated with lime dust, as shown in Figure 1. The purpose of the lime dust was to prevent the samples from adhering to the insulation board. Molten asphalt at a temperature of 425 to 450°F was mopped on to the felt, as shown in Figure 2. A second layer of felt was applied to the hot asphalt. Successive moppings of asphalt and layers of felt were applied until the required number of plies was completed. When the final coating of asphalt was sufficiently cool, the entire assembly was turned over and the bottom felt was coated with asphalt. Cut-outs 2 X 2 feet in size were taken at selected areas from each assembly near the center, as shown in Figure 3. The cut-outs were returned to the National Bureau of Standards together with the samples of felts and asphalt.

b) Laboratory Samples

The laboratory prepared samples were made to the same specifications as the field samples. The asphalt was heated in a thermostatically controlled electrically heated container. The asphalt was heated to about 300°F and stirred to insure uniform heating. The hot asphalt was applied between two 12 X 12 inch pieces of felt which were then placed in a hydraulic press using spacers to control the thickness of the asphalt adhesive. This process was repeated with appropriate sized spacers to produce the desired number of plies. The top and bottom surfaces were coated with asphalt using the hydraulic press with spacers to control thickness.

2.2 Test Specimen Preparation

The samples were chilled to about 32°F and dumbell-shaped specimens were cut out using a suitable die with the hydraulic press. Figure 4 shows the die and a typical test specimen.

Five specimens were cut in each direction (longitudinal and transverse to felt machine direction) to provide triplicate determinations of load-strain data and duplicate determinations for linear thermal expansion measurement.

2.3 Testing Procedure

The load-strain properties of the specimens were determined at 0°F using a universal testing machine equipped with a controlled temperature chamber. The gage length for strain calculations was defined as the distance between the jaws of the testing machine and was 4.5 in. A straining rate of 0.05 in. per minute (1.1% per minute) was used in each determination.

For linear thermal expansion measurements the dumbell-shaped specimens were fitted with gage points to receive a 5" Whittemore gage. The specimens were placed in a conditioning chamber and initial length measurements made at a temperature of 30°F. The chamber temperature was lowered to -30°F and measurements were again made. The linear thermal expansion coefficient was calculated from the change in length due to the 60° change in temperature.

3. RESULTS

Figures 5 and 6 compare field prepared and laboratory prepared samples with regard to strength and elongation properties. The field prepared samples showed higher values than did the laboratory prepared samples. This variation was attributed originally to non-uniformity of bitumen thickness of the field samples. However thickness measurements of samples indicated that less asphalt was used in the field specimens than in those prepared in the laboratory. This difference may have contributed to the observed differences. The tensile strength difference between longitudinal and transverse directions of the felt

in the samples was as expected. However the results indicate that the elongation property was generally unaffected by felt direction.

The physical properties of the built-up membranes are listed in Table 1. The average membrane thickness was measured with a micrometer caliper. The between ply thickness was measured on a tool makers microscope that has a movable stage driven by a micrometer screw. The between ply spreading rates were calculated from the thickness measurements using a value of one for specific gravity of the asphalt. The between ply spreading rate for the laboratory prepared samples was higher than that of the field prepared samples with the exception of membrane #9 were the spreading rates were equal.

A comparison of the values of thermal-shock resistance factors of laboratory specimens and field specimens (Table 2) indicates that the field specimens generally produced higher values than did the laboratory specimens. These differences are reflected by the values of the engineering properties.

3.1 Discussion of Results

The program was designed to measure the values of some engineering properties [breaking load, elongation, linear thermal expansion coefficient] of several types of built-up roof membranes prepared both under field conditions and in the laboratory. To our knowledge, this is the first time that such a comparison has been made. The field specimens were prepared in accordance with good roofing practices by experienced roofers under the supervision of trained personnel. During application, an attempt was made to prepare specimens to meet the requirements of accepted roofing specifications, i.e., with an application of the mopping asphalt at a spreading rate from 20 to 25 pounds per square between the plies of felt. The laboratory specimens were prepared by experienced research technicians under closely controlled conditions. The

asphalt adhesive was applied at about 25 pounds per square. The engineering properties of each set of specimens were measured under laboratory conditions. Under these circumstances, one would generally assume that the higher values would be obtained for the strength properties of the specimens prepared in the laboratory. The results, however, did not support this assumption. In fact, they showed that the field prepared specimens consistently gave the higher values for the breaking load. On the other hand, lower values were obtained for the coefficient of linear thermal expansion while the values for the elongation properties appeared to remain approximately the same for each type of specimen. Consequently, the values for the thermal-shock resistance factor, which were calculated from the results, were higher for the field specimens. This would indicate that the field prepared specimens would have the higher resistance to tension splitting due to rapid temperature change.

The question now arises as to how the results of the laboratory tests can be translated into information which can be readily used in field practice.

Strength-deformation characteristics of adhesive-adherend systems are affected by the thickness of the adhesive layer. The "strength-thickness" rule indicates that the strength of the adhesive-adherend system increases as the thickness of the film of the adhesive decreases. In a solid-asphalt-solid system subjected to tensile stresses, the existence of the strength-thickness rule has been confirmed by a number of investigators [4]. The results of the tests seem to support the "strength-thickness" rule. An initial interpretation of the test results of this program in terms of field practice indicates what apppears to be a very significant finding, i.e. the engineering properties improve as the thickness of the asphalt adhesive decreases. Assuming the results obtained in this series of tests are valid, this information could

produce a major impact on currently promulgated roofing specifications and application techniques which in turn could ultimately affect the performance of built-up roofing in service. A comparison of the thickness measurements between laboratory and field specimens indicated that the majority of the currently promulgated roofing specifications may not reflect the current roofing practices in respect to rates of application of asphalt adhesive. The results also indicated that the optimum amount of bitumen for between-the-ply moppings may be somewhat less than is currently described in most roofing specifications.

4. CONCLUSIONS AND RECOMMENDATIONS

Generally, the data reported in this paper indicate that field prepared specimens agree favorably with laboratory prepared specimens. More specifically, the results frequently reflected higher values for the thermal-shock resistance factor for field applied specimens. This may be due, in part, to the differences in the adhesive thickness observed between laboratory and field specimens.

We would not recommend, at this time, that changes be made in specifications or in roof application techniques based on the data reported herein since it is preliminary in nature. However, we do recommend that additional research be conducted to study the applicability of the "strength-thickness" rule to bitumenous built-up roofing membranes.

5. ACKNOWLEDGMENT

The authors acknowledge with gratefule appreciation the excellent cooperation of the Midwest Roofing Contractors Association including the financial support for the field portion of the program. Further the assistance of Mr. P. L. Morris, Vice-President, Sellers and Marquis Roofing Company is worthy of special mention.

6. REFERENCES

[1] W. C. Cullen, Effects of Thermal Shrinkage on Built-Up Roofing, NBS Monograph No. 89 (1965).

[2] W. C. Cullen, Solar Heating, Radiative Cooling and Thermal Movement - Their Effects on Built-Up Roofing, NBS Technical Note 231 (December 1963).

[3] W. C. Cullen, T. H. Boone, Thermal-Shock Resistance For Built-Up Membranes, NBS Building Science Series No. 9 (August 1967).

[4] K. Majidzadeh, M. Herrin, Strength-Thickness Relations of Solid-Asphalt-Solid Systems, ASTM Special Technical Publication No. 409 (1966).

Table 1. Physical Properties of Built-Up Roofing Membranes

Sample No. [1]	Membrane: No. of Plies	Membrane: Felts	Average Sample Thickness in.	Between Ply Asphalt Thickness in.	Between Ply Spreading Rate per 100 sq. ft.
1-L	3	Organic, Type 15	.32	.04	21
1-F			.19	.02	10
2-L	4	Organic, Type 15	.38	.04	21
2-F			.34	.03	16
3-L	3	Asbestos, Type 15	.28	.05	26
3-F			.19	.03	16
4-L	4	Asbestos, Type 15	.38	.05	26
4-F			.26	.03	16
5-L	3	Coated base sheet +	.34	.05	26
5-F		2 Organic Type 15	.22	.02	10
6-L	4	Coated base sheet +	.32	.04	21
6-F		3 Organic Type 15	.29	.02	10
7-L	2	Proprietary System	.27	.06	31
7-F		Heavyweight Asphalt Saturated Felt	.24	.02	10
8-L	2	Proprietary System	.24	.04	21
8-F		Asphalt Saturated and Coated Felt	.24	.03	10
9-L	2	Proprietary System	.18	.04	21
9-F		Asphalt-Impregnated Glass Fiber Mat (Felt)	.13	.04	21

[1] L = laboratory prepared samples, F = field prepared samples

Table 2. Test Results

Specimen No. 1/	Direction of Cut	S Breaking Load 2/ lb/in.	M Elongation Modulus 2/ $x10^4$	α Linear Thermal Expansion $x10^{-6}$	Thermal Shock Resistance Factor 3/
1-L	Longitudinal	350	2.5	14	1000
	Transverse	190	1.3	40	370
1-F	L	380	3.0	7	1850
	T	180	1.5	25	500
2-L	L	390	3.6	15	720
	T	250	2.5	34	460
2-F	L	500	3.7	12	1120
	T	250	2.3	36	300
3-L	L	210	2.7	14	550
	T	140	1.5	23	410
3-F	L	270	3.4	9	880
	T	180	2.1	18	460
4-L	L	230	3.3	12	580
	T	200	2.7	23	320
4-F	L	370	5.0	7	1045
	T	260	3.6	17	430
5-L	L	230	3.3	12	580
	T	200	2.7	23	320
5-F	L	310	3.3	8	1250
	T	180	2.1	16	540
6-L	L	480	4.2	8	1430
	T	260	1.4	37	410
6-F	L	470	4.4	7	1500
	T	230	2.6	14	640
7-L	L	370	3.4	13	840
	T	240	2.4	25	380
7-F	L	350	3.4	13	840
	T	230	2.2	26	390
8-L	L	290	3.3	17	520
	T	200	2.3	34	310
8-F	L	320	3.0	15	710
	T	160	1.8	34	270
9-L	L	110	1.7	28	110
	T	80	2.3	39	90
9-F	L	120	1.5	14	540
	T	90	2.2	22	200

1/ L = laboratory prepared samples. F = field prepared samples.

2/ at 0°F

3/ TSRF = $\frac{S}{M \alpha}$

FIGURE 1. Coating of insulation boards with lime dust to prevent adhering of field samples.

FIGURE 2. Application of hot asphalt to felt.

FIGURE 3. Removing of 2 X 2 foot cut-out from field prepared sample.

FIGURE 4. Cutting die, built-up roofing specimen and cross section of membrane.

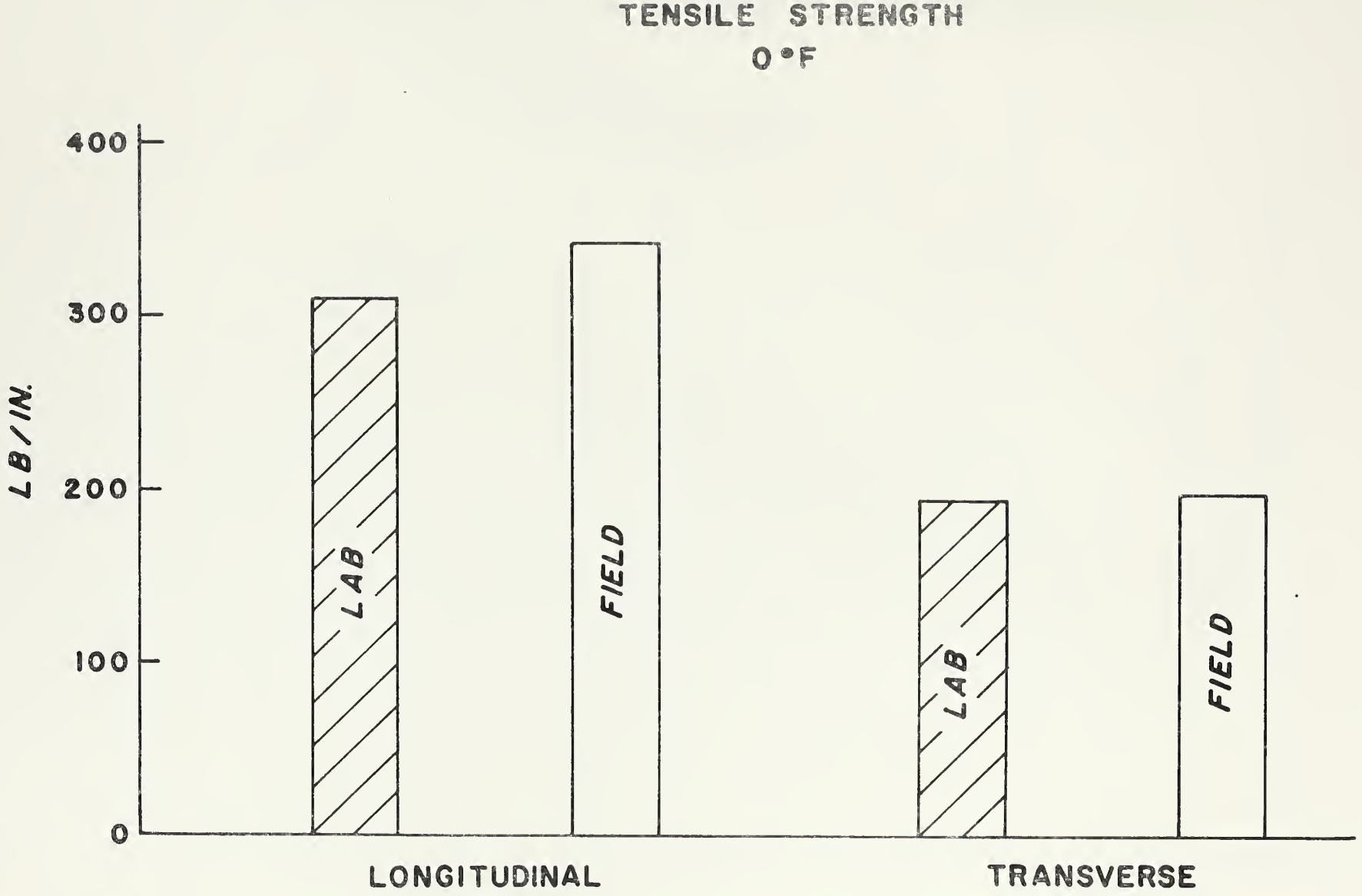

FIGURE 5. Comparison of the average results of tensile strength of laboratory and field specimens.

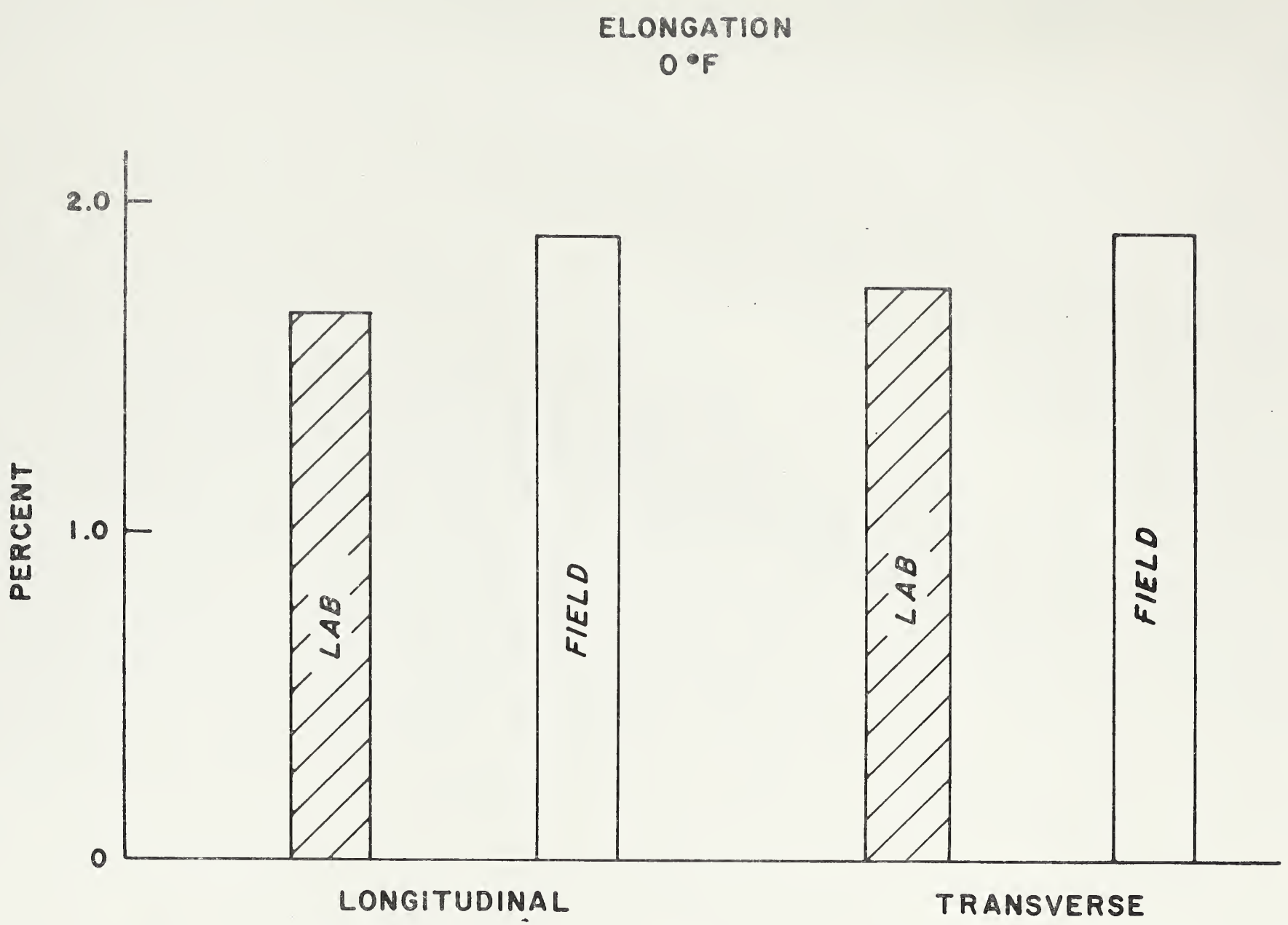

FIGURE 6. Comparison of the average results of the elongation of laboratory and field specimens.